STUDY ON RATE OF CONSOLIDATION OF SOFT CLAY USING SAND DRAIN AND PVD

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ABSTRACT: Whenever soft cohesive soil strata underlying a structure are unable to meet the basic requirement of safe bearing capacity and tolerable settlement, ground improvement is adopted. Both the design requirements can be fulfilled by consolidating the soil by applying a preload, before the construction of foundation. This consolidation of soil is normally accelerated with the use of vertical drains. Sand drains are conventionally adopted but nowadays synthetic or polymer based prefabricated vertical drains are becoming popular to enhance the speed of consolidation. Present study aims to compare the rate of acceleration of consolidation by providing different drains namely sand drain and band drain (PVD) along with different drainage direction namely vertical direction, radial direction alone and both vertical and radial direction of drainage. The ratio of sample diameter to drain diameter \((n)\) is considered as variable with values as 5.2, 10.4 and 14.2 using the 156mm diameter modified consolidation ring in the laboratory. In general, installation of sand drain and PVD accelerates the rate of consolidation. It is inferred that higher the drain diameter (i.e. smaller the n value), faster the rate of consolidation and therefore \(t_{50}\) value is less. Sand drain accelerates consolidation little faster than PVD.

**Keywords:** Radial consolidation, Sand drain, PVD

1 Introduction

Due to rapid urbanisation and industrialisation, there is a scarcity of suitable subsoil for construction. The engineers are forced to accept the available poor subsoil site for construction. These types of sites with unfavourable geotechnical properties need improvement. The soils of marine origin located along the coast are very soft and characterized by poor strength and high compressibility. There are numerous techniques to improve the soft clays such as preloading, band drains, thermal heating and freezing, electro-osmosis, stone column etc.

Preloading is the most popular and economic ground improvement technique. Since most compressible soils are characterised by very low permeability, depending on the thickness of clay bed and length of drainage path, consolidation may take a longer time and require a very high surcharge load. Installation of vertical drains can significantly reduce the preloading period by reducing the drainage path radically, because the consolidation time is directly proportional to the square of the length of the drainage path. Sand drains are widely adopted conventional method for increasing the rate of consolidation. With the increase application of geosynthetic materials in geotechnical engineering, synthetic or polymer based prefabricated vertical drains are becoming popular to enhance the speed of consolidation.

In order to select the most suitable method of draining for a given consistency in the field, there is a need to carryout comparative study on the effect of different drains namely sand drain and band drain (PVD) along with different drainage direction namely vertical direction, radial direction alone and both vertical and radial direction of drainage. Attention has been paid towards the possibilities for providing all the field conditions in the laboratory. And also, the ratio of sample diameter to drain diameter \((n)\) is considered as variable with values of 5.2, 10.4 and 14.2.

2 Experimental Program

2.1 Soil properties

The natural soil was collected from Velachery, which is located in Chennai and stored in the laboratory. The soil is classified as clay of High Plasticity (CH) with liquid limit of 68%, plastic limit of 29% and plasticity index of 39%.
2.2 Test procedure

The size of cylindrical mould for modified consolidation apparatus is 156mm diameter and 96mm height. The soft clay bed was prepared at soft consistency soil with the water content slightly greater than liquid limit. To study vertical consolidation characteristics mainly two way drainage was considered and the conventional test procedure was adopted. To study the radial consolidation characteristics, the soil was prepared at very soft consistency with 70% water content and a load of 12.5kPa was applied to the sample until 90% consolidation was over. After that the sample was unloaded and sand drain was formed by drilling the hole using sampling tube into the soft clay bed (consistency index is less than 20%) whose inner diameter almost equal to drain diameter by adopting non displacement method of drilling. The hole was then backfilled with washed clean sand at loose density. In case of PVD, it was installed by displacement method. The consolidation ring with clay sample provided with drain was fitted in the consolidation set up and the same load is again applied and kept for one day before proceeding to the next load increment.

The test was then continued using a loading sequence which would successively apply stress of 25, 50 and 100kPa. For each load increment, after the application of load, the dial gauge readings taken using the time sequence 0, 0.25, 0.5, 1, 2, 2.25, 4, 6.25, 9, 12.25, 16, 20.25, 25, 30, 36, 49, 64, 81min, etc., upto 24 hours. A load period of 24 hours was adopted for all load increments. The rubber sheet having central hole with diameter of drain was used both at top and bottom of the soil to restrict the vertical drainage and thereby to study only the radial consolidation characteristics. For single drain, the ratio of sample diameter to drain diameter (n) is considered as variable with values as 5.2, 10.4 and 14.2 whose drain diameter are 30mm, 15mm and 11mm respectively in case of sand drain and width of 43mm, 19.6mm and 13.3mm respectively in case of PVD having thickness of 4mm. Three number of drains was also considered (n=5.068) with drain diameter of 11mm and PVD width of 13.3mm.

In order to find the Coefficient of vertical consolidation and time required for 50% consolidation ($t_{50}$), test results thus obtained were plotted in Casagrande’s logarithmic time method with the exception that $t_2=2t_1$ instead of $t_2=4t_1$.

3 Results and comparisons

3.1 Comparison of $C_v$ and $C_r$ for soft clay with PVDs and with sand drains

The time factor of 50% consolidation for radial consolidation were taken from table 3 of IS 15284 (part 2)-2004 as 0.0833, 0.1395 and 0.1654 for required n values. In order to compare the rate of settlement, the coefficients of consolidation for various cases are tabulated in Tables 1 and 2 and the ratio of coefficient of radial consolidation to coefficient of vertical consolidation ($C_r/C_v$) are tabulated in Table 3.

Table 1 Coefficient of vertical consolidation

<table>
<thead>
<tr>
<th>Consolidation pressure</th>
<th>25kPa</th>
<th>50kPa</th>
<th>100kPa</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_v$ ($10^{-3}$cm$^2$/sec)</td>
<td>0.300</td>
<td>0.273</td>
<td>0.206</td>
<td>0.2597</td>
</tr>
</tbody>
</table>

Table 2 Variation of Coefficient of radial consolidation

<table>
<thead>
<tr>
<th>Ratio of sample to drain diameter (n)</th>
<th>Type of drain</th>
<th>Consolization pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25kPa</td>
</tr>
<tr>
<td>5.2</td>
<td>PVD</td>
<td>2.33</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>2.79</td>
</tr>
<tr>
<td>10.4</td>
<td>PVD</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>4.18</td>
</tr>
<tr>
<td>14.18</td>
<td>PVD</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>3.77</td>
</tr>
</tbody>
</table>

Table 3 Variation of Ratio of Coefficient of Radial Consolidation to Coefficient of Vertical Consolidation

<table>
<thead>
<tr>
<th>Ratio of sample to drain diameter (n)</th>
<th>Type of drain</th>
<th>$C_r/C_v$ ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2</td>
<td>PVD</td>
<td>6.55</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>10.52</td>
</tr>
<tr>
<td>10.4</td>
<td>PVD</td>
<td>9.25</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>15.41</td>
</tr>
<tr>
<td>14.18</td>
<td>PVD</td>
<td>9.86</td>
</tr>
<tr>
<td></td>
<td>Sand drain</td>
<td>18</td>
</tr>
</tbody>
</table>
It is found that the coefficient of rate of consolidation is higher in the horizontal direction than in the vertical direction. The average $C_r/C_v$ ratio of different $n$ values for PVD and Sand drain are 8.55 and 14.64 respectively. The coefficient of radial consolidation is higher in sand drain than PVD.

The settlement logarithmic time plot for soft clay with PVD and sand drain for three different $n$ values 5.2, 10.4 and 14.2 with vertical and radial drainage for pressure increments of 50-100kPa were compared as shown in figure 1 and 2 respectively. Irrespective of drainage conditions and pressure increment $t_{50}$ for $n$ value of 5.2 is lesser than $t_{50}$ for 10.4 and 14.2 value. Higher the drain diameter lesser the $t_{50}$ value, faster the rate of consolidation. Therefore $n=5.2$ was considered as efficient $n$ value.

3.2 Comparison of rate of consolidation with single and with 3 drain

Consolidation test were carried out with three drains instead of single drain with same drain diameter. As number of drain increased, rate of consolidation is accelerated as shown in figure 3 and 4. The settlement logarithmic time plot for soft clay with single ($n=5.2$) and with 3 drain ($n=5.068$) are compared because both having almost same $n$ value (but different diameter) for vertical and radial drainage at pressure increment 12.5-25kPa, were shown in figure 5 to 6 respectively. It is inferred that for a given $n$ value single larger drain is effective instead of providing three smaller drains.

It is found that the coefficient of rate of consolidation is higher in the horizontal direction than in the vertical direction. The average $C_r/C_v$ ratio of different $n$ values for PVD and Sand drain are 8.55 and 14.64 respectively. The coefficient of radial consolidation is higher in sand drain than PVD.

![Figure 1](image1.png)

**Fig. 1** Comparative plot of three $n$ values with PVD for both vertical and radial drainage at the pressure increment of 50-100kPa

![Figure 2](image2.png)

**Fig. 2** Comparative plot of three $n$ values with Sand drain for both vertical and radial drainage at the pressure increment of 50-100kPa

![Figure 3](image3.png)

**Fig. 3** Comparative plot with single and with 3 PVD of equal drain diameter for vertical and radial drainage at the pressure of 12.5-25kPa

![Figure 4](image4.png)

**Fig. 4** Comparative plot with single and with 3 sand drain of equal drain diameter for vertical and radial drainage at the pressure of 12.5-25kPa
Fig. 5 Comparative plot with single and with 3 PVD of equal n value for vertical and radial drainage at the pressure of 12.5-25kPa

Fig. 6 Comparative plot with single and with 3 sand drain of equal n value for vertical and radial drainage at the pressure of 12.5-25kPa

4 Conclusion

Based on the Settlement-time data obtained from the consolidation test on soft clay with and without drains, following general conclusion may be drawn. In general, installation of sand drain and PVD accelerates the rate of consolidation. Irrespective of n values $t_{50}$ value for vertical and radial drainage was less when compared to radial drainage. Higher the drain diameter lesser the $t_{50}$ value, faster the rate of consolidation. Therefore n=5.2 was considered as efficient n value. It is found that the coefficient of rate of consolidation is higher in the horizontal direction than in the vertical direction. Coefficient of consolidation for radial drainage was approximately 8.55 times and 14.64 times as that of vertical consolidation for PVD and Sand drains respectively. Sand drain accelerates 1.7 times faster than PVD. The variation of Compression Index and coefficient of compressibility for different cases was marginal. And the value of coefficient of compressibility decreases as the pressure increases. Sand drain may be effectively used in accelerating rate of consolidation.

REFERENCES


